ORIGINAL RESEARCH

Mexican Queso Chihuahua: rheology of fresh cheese†

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Rheological properties of fresh Queso Chihuahua made from raw milk (RM) or pasteurized milk (PM) were characterized using texture profile, torsion and small amplitude oscillatory shear analyses. Although the rheological properties varied significantly among the different brands with overlapping ranges for the individual RM and PM cheese brands, overall the PM cheeses were harder, chewier and more cohesive but had lower viscoelastic values than the RM cheeses. Establishing the rheological properties of Mexican Queso Chihuahua increases our understanding of the quality traits of Hispanic-style cheeses and provides a foundation for maintaining the traditional texture of the cheese.

Keywords Hispanic cheese, Pasteurized milk, Raw milk, Rheology.

INTRODUCTION

The cheeses developed in México, Latin America and the Caribbean are referred to as Hispanic-style cheeses and most are based on European cheeses but modified to accommodate local preferences and cheesemaking conditions (Van Hekken and Farkye 2003). Limited data on the cheeses have hindered defining the cheeses further. One of the major cheeses produced in northern México, Queso Chihuahua (also known as Queso Chester), is a semihard, minimally aged (typically consumed within 2–4 weeks after manufacture) variation of young Cheddar cheese developed by the Mennonite communities in the state of Chihuahua. The Mexican Official Standards require Queso Chihuahuas to contain a minimum of 22.0% protein and 25.0% fat, a maximum of 45.0% moisture and 3.0% salt, and maximum mesophilic aerobic microbial counts of 5×10^5 cfu/g and moulds/yeast counts of 1×10^2 cfu/g (DGN 1994). Surveys of commercial Queso Chihuahua showed that the cheese contains 21–24% fat, 26% protein and 2.1–2.3% salt (Diaz-Cinco *et al*. 1992, 1998; Saltijeral *et al*. 1999). Diaz-Cinco *et al*. (1992) reported that the moisture content of freshly made Queso Chihuahua decreased from 58.4% at day 0 to 32.5–35.7% moisture by day 12. Saltijeral *et al*. (1999) reported a moisture content of 35% for Queso Chihuahuas of unknown age obtained in Mexico City. Although all commercial cheeses in the three studies mentioned above tested negative for pathogenic micro-organisms, they contained total plate counts above the Mexican official microbiological standards (Direccion General de Normas 1994). Although chemical and microbiological composition of Queso Chihuahua has been investigated, other properties that define the cheese have not been studied.

Texture is one of the critical quality traits that consumers look for when eating cheese. Hispanic-style cheeses are known by generic texture descriptors (rubbery, crumbly) but rheological measurements for most of the cheeses are unavailable in the published work. Queso Chihuahua is described as being '… a cross between Cheddar and brick cheese …' and with a '… body medium hard with crumbly texture …' (Kosikowski and Mistry 1997a). Texture can be characterized using a variety of tests and assays. Compositional data, including protein profiles, quantify the amount of milk components in the cheese matrix, whereas the rheological properties give insight into the construction of the matrix by measuring its responses to applied mechanical stress and strain. Different rheological tests examine different aspects of the components' interactions within the cheese matrix (Tunick 2000) and are used to compare different styles of cheese and to characterize cheeses as they age (Tunick and Van Hekken 2002, 2003). Rheological definitions and baselines can be used to evaluate changes in texture because of processing and post-production modifications and to gauge the quality, uniformity and shelf life of the cheese.

†Mention of trade names or commercial products in the article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

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ARS-USDA, in collaboration with the Centro de Investigación en Alimentiación y Desarrollo (CIAD), examined the quality traits of commercial Queso Chihuahua manufactured in the state of Chihuahua, Mexico, which were made using either raw milk (RM) or pasteurized milk (PM). The project characterized a variety of aspects of the cheese, including the manufacture procedures, composition (Tunick *et al*., manuscript submitted), microbiological populations of 10-day-old RM and PM cheeses (Bricker *et al*. 2005) and effects of aging on the rheology of the cheese (Tunick *et al*. 2007). This portion of the study characterized the rheological properties of 10-day-old RM and PM Queso Chihuahua.

MATERIALS AND METHODS

Commercial cheeses

Fourteen different brands of semihard Queso Chihuahuas were obtained from 12 different commercial cheese manufacturers throughout the state of Chihuahua, Mexico. Nine brands of cheese (designated brands A to H, and J) were made from RM (no starter culture added) and five brands of cheese (designated brands L to N, P and Q) were made from PM (commercial starter culture added); brand P was made from milk heated to 73°C for 3 s. Cheeses placed in the PM category showed alkaline phosphatase inactivation using the Charm Pas Lite test (Charm Sciences, Inc., Lawrence, MA, USA).

Discussions with the manufacturers indicated that cheesemaking steps were based on Cheddar cheesemaking protocols with slight procedural modifications, which varied among the different cheese plants. All cheeses were packaged in plastic heat-shrink wrap. Three 1-kg blocks of cheese were obtained from each manufacturer within 2 days of manufacture and kept in coolers containing an adequate number of cool packs to maintain the cheese near 4°C until overnight delivery to the Dairy Processing and Products Research Unit (DPPRU), ARS, Wyndmoor, PA, USA. Over an 8-month period, a total of five shipments were sent to the DPPRU, providing a total of 42 blocks of cheese for analysis. Cheeses were stored at 4°C and evaluated at day 10 after manufacture.

Composition of commercial cheeses

Composition was determined for each block of cheese. Moisture was measured in triplicate using force-draft oven method 948.12 (AOAC 2000). Fat content was determined in duplicate using the modified Babcock method (Kosikowski and Mistry 1997b). Nitrogen content of the cheeses were measured in duplicate using a FP-2000 nitrogen analyser (LECO Corp., St. Joesph, MI, USA) and total protein content was calculated by multiplying the percent of nitrogen by 6.38. NaCl levels were determined using high-range chloride titrators (Hach Co., Loveland, CO, USA).

Protein distribution

Cheese samples from one block of cheese per brand were stored at −35°C until water-soluble proteins were extracted for sodium dodecyl-sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) using the procedure described by Tunick *et al*. (1995). Proteins were separated on 20% homogenous gel using the PhastSystem (American Pharmacia Corp., Piscataway, NJ, USA). After staining with Coomassie blue, gels were scanned (model 375 A Personal Densitometer SI, Molecular Dynamics, Sunnyvale, CA, USA) and protein distribution calculated using ImageQuant (version 4.2, Molecular Dynamics). Each lane was analysed in duplicate and major bands were identified as α_{S1}-CN, α_{S2}-CN, β-CN and κ-CN (f1-105). Casein fragments were divided into molecular mass ranges (22 kDa, 20–18.5 kDa, 15–18 kDa and 10–14 kDa). Peptides that were smaller than 10 kDa were not tracked because of migration off the gel and poor staining properties.

Rheological properties

Rheological properties were determined for each block of cheese. Each cheese block was divided into portions and warmed to room temperature (22°C) prior to the preparation of samples. All tests were conducted at 22 ± 1°C.

Torsion analysis was conducted using a torsion gelometer (Gel Consultants, Inc., Raleigh, NC, USA) using the methodology described by Foegeding (1992). Four plugs (27.5-mm length, 15-mm diameter) were milled to the appropriate capstan shape (centres milled to 10-mm diameter to minimize the influence of geometry on the calculations). Samples were secured in the gelometer and twisted at 2.5 r.p.m. until the sample fractured. Gelometer software collected shear stress and shear strain at point of fracture and calculated the shear rigidity (ratio of stress to strain) at the point of fracture.

Texture profile analysis was conducted using a universal testing machine (Sintech, Model SM-25-155, Material Testing Products Systems Corp., Eden Prairie, MN, USA) using the methodology described by Tunick and Van Hekken (2002). Four cylindrical plugs (14.5-mm diameter and height) from each cheese sample were compressed by 75% twice using a crosshead speed of 100 mm/min. Hardness, cohesiveness and springiness were calculated by the instrument’s software from the generated force–distance curves. Chewiness was calculated by multiplying the hardness, springiness and cohesiveness values.

Small amplitude oscillatory shear analysis was conducted using a Dynamic Analyser (model

RDA-700, Rheometrics Scientific, Piscataway, NJ, USA) as described by Tunick *et al*. (1995). Discs (25.4 × 4–5 mm) were glued to parallel plates and the linear viscoelastic range for each cheese was determined by a strain sweep. Frequency sweeps (0.1–100 rad/s) were conducted in triplicate at 0.8% strain and elastic and viscous modulus were used by the instrument's software to calculate the complex viscosity; values presented were obtained at 10 rad/s.

Statistical analyses

Rheological data were analysed using (1) the general linear model followed by Bonferroni *t*-test ($P < 0.05$) to determine variation among milk treatments (RM vs PM) and brands, (2) principal component analysis (PCA) by brands with rheology properties as the variables to determine similarities or clustering of the brands, and (3) correlation coefficients were calculated between components and rheological properties (SAS 1999).

RESULTS AND DISCUSSION

All Queso Chihuahuas consisted of firmly packed curds with minimal air pockets between major curd divisions. All cheeses were pale yellow and few brands had a mottled appearance. Few of the RM cheeses had pinhole gas formations.

Composition of commercial cheeses

The compositional content of the commercial Queso Chihuahua (Table 1) varied among the individual brands with the means for the PM and RM cheeses overlapping. The composition for the PM cheeses was more uniform (lowest and highest values only varied by 1.6% for moisture, 3.3% for protein and 2.3% for fat) when compared with the RM cheeses (varied by 6.4% for moisture, 5.2% for protein and 7.4% for fat) and suggested that heat treatment of the cheesemilk resulted in a more uniform starting material, most likely because of the reduction of the microflora and inactivation of some enzymes. Salt concentrations ranged from 1.0–1.5% for all brands and moisture in nonfat substance (MNFS) ranged from 57–63% (except brand H). The PM cheeses (except brand Q) had the highest values for salt and MNFS. The fat in dry matter (FDM) ranged from 50.9–57.2% with the PM cheeses having the highest (brand P) and the lowest (brand Q) values. All brands conformed to the chemical requirements for the Mexican Official Standards for Mennonite-style (Direccion General de Normas 1994). Protein and fat concentrations were similar to those reported earlier (Diaz-Cinco *et al*. 1992, 1998; Saltijeral *et al*. 1999). Moisture contents were above 40% for all of the PM cheeses and above 39% for most of the RM cheeses, which agreed with the larger sampling of the brands reported by Tunick *et al*. (2007). Only one RM cheese (brand H) had a moisture level near the 35% moisture reported by Diaz-Cinco *et al*. (1992) and Saltijeral *et al*. (1999) and may be related to longer air drying and packaging of this particular brand of cheese. Overall, the moisture content of Queso Chihuahua was higher than typical Cheddar cheese (maximum of 39% moisture).

Protein distribution

Protein profiles of cheeses at 10 days after manufacture (Table 1) showed variation among brands, although the overall means for the intact proteins showed similar levels in the RM and PM cheeses. Although some proteolytic products were expected in cheeses at 10 days after manufacture, few of the Queso Chihuahuas had higher levels of casein peptides than expected. Brand G had a high level of peptides in the 18.5–20 kDa range, the range that includes large peptides from the chymosin hydrolysis of α_{S1}-CN and β-CN. Brand F had high levels of smaller peptides in the 10–14 kDa range, the range that includes the plasmin-generated β-CN (f104–209) and (f106–209) peptides. Brand M, however, a PM cheese, had the highest level of peptides in the 22 kDa range, typically the location for chymosin-generated α_{S1}-CN (f24–199). Brand L had the highest level of casein fragments in the 15–18 kDa range, which included the chymosin-generated κ-CN (f1–105).

The appearance of gas pinholes and higher levels of casein fragments in some of the RM cheeses suggested that the microflora may be responsible for the higher degree of hydrolysis. Tunick *et al*. (2007) reported that the cheeses used in this study tested negative for *Listeria monocytogenes*, *Escherica coli* 0157:H7, *Campylobacter* spp., and *Staphococcal aureus* enterotoxin; the aerobic counts were 7–9 $\log_{10}$ cfu/g for the RM cheeses and 6–8 $\log_{10}$ cfu/g for the PM cheeses. The counts are above the recommended maximum mesophilic aerobic microbial counts set by the (Direccion General de Normas 1994) and strongly suggest stricter sanitation controls in the manufacture of the cheese. Bricker *et al*. (2005) characterized the microbial population in 10 of the 14 commercial cheeses in this study and reported similar mesophilic and thermophilic lactococci concentrations in both RM and PM cheeses although lactobacilli counts were slightly lower in PM cheeses. The RM cheeses contained coliforms, enterococci and coagulase-positive staphylococci that were not present in the PM cheeses. The diverse microflora will influence the proteolysis of the cheese matrix, and therefore, the quality traits of the Queso Chihuahua.

Rheological properties

The texture of cheese is influenced by many factors before, during and after cheesemaking. Rheology

Table 1 Summary of the composition and protein distribution for the different brands of Queso Chihuahua. Raw milk cheeses are brands A to H and J, and pasteurized milk cheeses are brands L to N, P and Q. Protein distributions were calculated from SDS-PAGE gels analysed using a densitometer

							Protein and peptide distribution (%)						
	Cheese composition (%)						*Caseins*			*Protein fragments*			
Brand	*Moisture*	*Protein*	*Fat*	*Salt*	*MNFS*	*FDM*	α_{S2}-*CN*	α_{S1}-*CN*	β-*CN*	*22 kDa*	*18.5–22 kDa*	*15–18 kDa*	*10–14 kDa*
Raw milk cheeses													
A	40.4 bcd	22.4 f	34.7 a	1.10 c	59.8 bcde	56.5 ab	6.2 bc	29.1 ab	27.6 bc	0.0 e	13.5 bc	11.2 c	6.9 bcde
B	39.4 d	25.3 bcd	32.0 bcde	1.06 c	58.3 cde	52.8 abcd	8.6 ab	29.2 ab	30.6 abc	4.3 cd	7.8 de	12.6 bc	5.9 cdef
C	41.3 abc	22.9 f	32.7 abc	1.16 bc	61.7 ab	55.6 abc	9.0 ab	25.6 bc	34.1 a	4.6 cd	7.6 de	13.1 abc	4.4 f
D	41.2 abcd	24.3 cde	30.8 cdef	1.23 bc	57.6 ef	52.5 bcd	8.6 ab	24.9 bcd	31.3 abc	4.9 cd	9.1 cde	14.1 abc	5.1 def
E	38.9 e	27.3 a	27.3 g	1.19 bc	58.4 bcde	55.3 abcd	6.8 abc	21.8 d	32.9 a	6.4 bc	9.8 bcde	14.6 abc	7.1 bcde
F	39.7 bcd	26.6 ab	29.9 e	1.05 c	58.1 de	53.1 abcd	5.0 c	18.9 de	26.9 c	4.8 cd	14.9 ab	14.9 abc	13.3 a
G	41.2 abcd	23.8 def	28.8 fg	1.34 ab	59.5 bcde	51.6 cd	6.5 abc	19.4 cde	22.1 d	7.6 b	20.2 a	13.3 abc	9.2 b
H	36.5 e	25.1 bcd	33.0 ab	1.18 bc	54.5 f	52.0 bcd	7.4 abc	23.1 bcd	32.4 a	5.4 bc	10.2 bcde	13.2 abc	7.8 bc
J	39.1 cd	22.1 f	33.3 ab	1.06 c	57.5 ef	53.3 abcd	8.6 ab	24.5 bcd	32.0 ab	6.5 bc	7.6 de	13.0 bc	5.3 def
RMA	40.0	24.0	32.0	1.15	58.6	53.7	7.4	24.0	30.0	4.9	11.2	13.3	7.2
Pasteurized milk cheeses													
L	41.1 abcd	23.8 def	32.1 bcde	1.5 a	60.7 abcde	55.7 abc	9.3 a	22.8 cd	31.3 abc	4.6 cd	7.9 de	18.4 a	4.9 def
M	41.2 abcd	23.7 def	30.3 def	1.5 a	61.6 abc	54.3 abcd	7.2 abc	13.6 e	30.3 abc	10.3 a	12.9 bcd	15.0 abc	9.3 b
N	41.9 ab	25.8 abc	32.1 bcde	1.40 ab	61.5 abcd	55.2 abcd	8.9 ab	29.2 ab	27.4 bc	2.6 de	8.4 cde	14.8 abc	7.3 bcd
P	42.4 a	24.6 cde	32.4 bcd	1.50 a	62.7 a	57.2 a	6.9 abc	33.3 a	33.2 a	0.0 e	6.3 e	13.6 abc	4.7 e
Q	40.8 abcd	27.0 ab	30.1 ef	1.18 bc	58.5 bcde	50.9 d	8.2 ab	23.7 bcd	29.4 abc	5.9 bc	9.9 bcde	16.7 ab	5.2 def
PMA	41.5	25.1	31.5	1.42	61.0	54.6	8.3	24.9	30.0	4.3	8.8	15.9	6.2

[1]does not include the minor whey proteins; [2]includes κ-CN (f1-105).

a, b, c, d, e, f – mean values in columns that are not sharing the same letter are significantly ($P < 0.05$) different. PMA, pasteurized milk cheese averaged mean; RMA, raw milk cheeses averaged mean; FDM, fat in dry matter; MNFS, moisture in nonfat substance.

gives insight into the impact of those factors by measuring the response of cheese structure to different applied forces.

The fracture properties for Queso Chihuahua varied significantly among the different commercial brands (Table 2), although the ranges and overall means for the RM and PM cheeses were not significantly ($P < 0.05$) different. Shear stress, the amount of force required to fracture the cheese matrix, ranged from 33.0–60.4 kPa for Queso Chihuahua; 11 of the 14 brands ranged from 33–50 kPa. Shear strain, the degree of deformation the cheese matrix can withstand before failure, ranged from 0.96–1.39. The shear rigidity, the ratio of shear stress : shear strain, ranged from 24.8–52.9 kPa. No significant correlations were found between the torsion properties and composition of the Queso Chihuahua.

The overall means for the torsion fracture properties of RM and PM Queso Chihuahuas were similar but not identical to other European and American cheeses of the same age (Table 3; Tunick

Table 2 Summary of the rheological properties of the different brands of Queso Chihuahua. Raw milk cheeses are brands A to H and J, and pasteurized milk cheeses are brands L to N, P and Q. RMA, raw milk cheeses averaged mean, PMA, pasteurized milk cheese averaged mean

	Torsion analysis			*Texture profile analysis*				*Small amplitude oscillatory shear analysis*		
	Shear stres (kPa)	*Shear strain*	*Shear rigid (kPa)*	*Hardness (N)*	*Chewiness (mJ)*	*Cohesiveness*	*Springiness (mm)*	*Elastic modulus (kPa)*	*Viscous modulus (kPa)*	*Complex viscosity (kPa)*
Raw milk cheeses										
A	38.4 cd	1.38 a	28.3 e	54.3 ef	121 cde	0.27 abcd	8.04 ef	46.4 cd	13.8 cde	4.84 cd
B	38.9 cd	1.31 abc	30.6 def	47.9 ef	116 de	0.25 cd	9.58 abcd	51.0 cd	17.4 bcd	5.39 cd
C	33.0 d	1.19 abcd	31.5 def	39.0 f	87 e	0.24 de	9.34 abcd	50.3 cd	15.1 bcde	5.25 cd
D	43.1 bcd	0.96 e	45.0 abcde	50.2 def	101 de	0.19 e	10.4 a	86.0 a	25.2 a	8.95 a
E	55.7 ab	1.14 bcde	49.8 abc	74.8 ab	175 ab	0.28 abcd	8.54 def	76.6 ab	20.4 abc	7.93 ab
F	35.3 cd	1.03 de	34.4 bcdef	43.3 ef	98 de	0.24 de	9.58 abcd	83.8 ab	25.5 a	8.76 a
G	37.9 cd	1.11 cde	35.7 abcdef	38.6 f	83 e	0.25 d	8.80 cdef	46.0 cd	13.5 de	4.80 cd
H	60.4 a	1.19 abcd	52.9 a	70.9 abc	172 abc	0.26 bcd	9.12 bcde	90.0 a	24.5 a	9.33 a
J	46.8 abcd	1.13 bcde	44.0 abcdef	54.2 def	143 bcd	0.27 abcd	9.64 abcd	74.8 ab	20.9 ab	7.77 ab
RMA	43.3	1.16	38.8	52.6	122	0.25	9.23	67.2	19.6	7.00
Pasteurized milk cheeses										
L	48.7 abcd	0.97 e	52.4 ab	57.4 cde	144 bcd	0.25 d	10.0 ab	50.3 cd	15.3 bcde	5.24 cd
M	33.4 cd	1.35 ab	24.8 f	43.6 ef	134 bcde	0.31 a	9.91 abc	79.4 ab	24.2 a	8.30 ab
N	57.4 ab	1.20 abcd	47.9 abcd	77.4 ab	202 a	0.30 abc	8.70 def	44.1 cd	14.7 bcde	4.65 cd
P	49.2 abc	0.96 e	51.4 ab	85.6 a	204 a	0.31 ab	7.80 f	61.6 bc	16.5 bcde	6.38 bc
Q	41.8 bcd	1.29 abc	32.7 cdef	66.3 bcd	180 ab	0.27 abcd	9.91 abc	29.4 d	10.0 e	3.08 d
PMA	44.3	1.18	39.3	66.1	173	0.29	9.26	55.3	16.9	5.78

a, b, c, d, e, f – mean values in columns not sharing the same letter are significantly different ($P < 0.05$).

Table 3 Comparison of rheological properties between Queso Chihuahuas made with raw milk (RM) or pasteurized milk (PM) and other young cheese reported by Tunick and Van Hekken (*5*)

		Torsion			*Texture profile analysis*				*Viscoelastic properties*		
	Age (day)	*Shear stress (kPa)*	*Shear strain*	*Shear rigidity (kPa)*	*Hardness (N)*	*Chewiness (mJ)*	*Cohesiveness*	*Springiness (mm)*	*Elastic modulus (kPa)*	*Viscous modulus (kPa)*	*Complex viscosity (kPa.s)*
Brick	7	55.9	1.33	42.0	88.6	207	0.27	8.64	35.4	13.3	3.78
Cheddar	12	42.9	0.83	51.9	46.5	84	0.21	8.57	75.3	30.0	8.13
Colby	10	49.8	1.13	44.1	73.8	177	0.28	8.55	47.1	18.4	5.07
Havarti	15	40.7	1.27	32.0	56.9	225	0.39	10.16	83.3	25.6	8.72
Mozzarella	7	48.5	1.56	31.1	68.0	270	0.41	9.70	35.9	13.6	3.83
Queso Chihuahua											
RM	10	43.3	1.16	38.8	52.6	122	0.25	9.23	67.7	19.6	7.00
PM	10	44.3	1.18	39.3	66.1	173	0.29	9.26	55.3	16.9	5.78

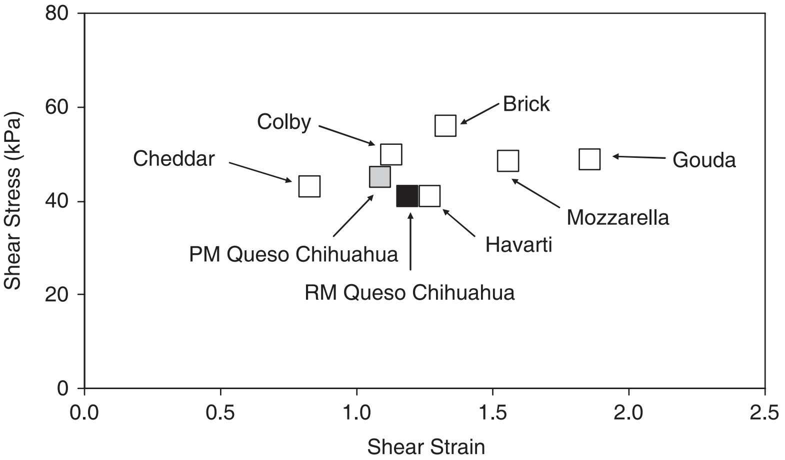

Figure 1 Texture map of torsion data (shear stress vs shear strain) for overall averages for Queso Chihuahua made from raw milk (RM) and pasteurized milk (PM) compared to other popular cheeses (Tunick and Van Hekken 2002). Size of the squares does not represent the degree of variation within denoted sample.

and Van Hekken 2002). The Queso Chihuahuas required similar force for fracture as fresh Cheddar, tolerated deformation similar to Colby cheese and had shear rigidity values between Havarti and brick cheeses. Although Queso Chihuahuas required similar shear for fracture as Cheddar cheese, Cheddar was a more rigid cheese that fractured at lower strain. To better illustrate the relationships among the fracture properties, cheeses' shear stress were plotted against their shear strain (Figure 1). The PM Queso Chihuahua was similar to fresh Colby, whereas the RM cheeses were similar to fresh Havarti, especially considering the wide range of shear stress and strain measured for the individual brands of Queso Chihuahua. The Colby comparison is not surprising as it too is made using steps based on the Cheddar cheesemaking procedures using PM. Kosikowski and Mistry (1997b) described Mexican Queso Chihuahua as having a texture similar to Cheddar and brick. The torsion data separated young brick and Cheddar into distinct areas on the graph, with Colby and PM Queso Chihuahuas located between them. The RM Queso Chihuahua was very similar to Havarti. The brick and Havarti compared here are both bacteria surface-ripened cheeses, yet a modification in the salting step resulted in Havarti having a softer texture (Kosikowski and Mistry 1997b). Further research will determine if the microflora in the RM Queso Chihuahuas contain any of the aerobic bacteria typically added to brick and Havarti cheeses.

The data from the double compression tests (texture profile analysis) showed significant variation among the different manufacturers for hardness, chewiness, cohesiveness and springiness (Table 2). Hardness, the force required for the first compression, ranged from 38.6–74.8 N for RM cheeses and 43.6–85.6 N for PM cheeses. Chewiness, the amount of work required for double compression, ranged from 83–175 mJ for RM cheeses and 134–204 mJ for PM cheeses. Cohesiveness, related to the ability of the cheese matrix to hold together after compression, ranged from 0.19–0.28 for RM cheeses and 0.25–0.31 for PM cheeses. Springiness, a measure of the ability of the cheese to return to its original height after the first compression, ranged from 8.04–10.4 mm for RM cheese and 7.80–10.0 mm for PM cheese. Although there were considerable overlaps among the different brands of Queso Chihuahua, based on the overall means, the PM cheese was significantly harder, chewier and more cohesive than the RM cheese. Compared to the texture profile analysis properties of other fresh cheeses (Table 3; Tunick and Van Hekken 2002), the PM Queso Chihuahua was similar in hardness to mozzarella, whereas RM Queso Chihuahua was similar to Havarti. The PM Queso Chihuahua was similar to Colby in chewiness. The RM and PM Queso Chihuahuas were similar to brick and Colby in cohesiveness. No significant correlations were found between the compression properties and composition of the Queso Chihuahua.

The viscoelastic properties, which are indicative of the molecular bond strength within the cheese matrix, showed significant variation among the different brands with considerable overlap among the RM and PM cheeses (Table 2). The elastic modulus ranged from 46.0–90.0 kPa for RM cheeses and 29.4–79.4 kPa for PM cheeses. The elastic modulus ranged from 13.5–25.5 kPa for RM cheeses and 10.0–24.2 kPa for PM cheeses. The complex viscosity ranged from 4.80–9.33 kPa.s for RM cheeses and 3.08–8.30 kPa.s for PM cheeses. The overall means for the viscoelastic properties of RM cheeses were significantly higher than the PM cheeses. Based on the overall means for the viscoelastic properties, the RM and PM Queso Chihuahuas ranked between young Colby and Cheddar for elastic modulus and complex viscosity, and were similar to Colby in viscous modulus. No significant correlations were found between the viscoelastic properties and composition of the Queso Chihuahua.

Principal component analysis, a statistical approach to examine the impact of multiple factors, determined that the first component accounted for 39.8% of the total variation, whereas the second component accounted for 33.0% of the variation. The correlation matrix showed strong relationships between the viscoelastic properties (elastic modulus to complex viscosity, 0.99; elastic modulus to viscous modulus, 0.98; and viscous modulus to complex viscosity, 0.98), and, to a lesser degree, among other rheological properties (shear stress and shear rigidity, 0.92; hardness and chewiness,

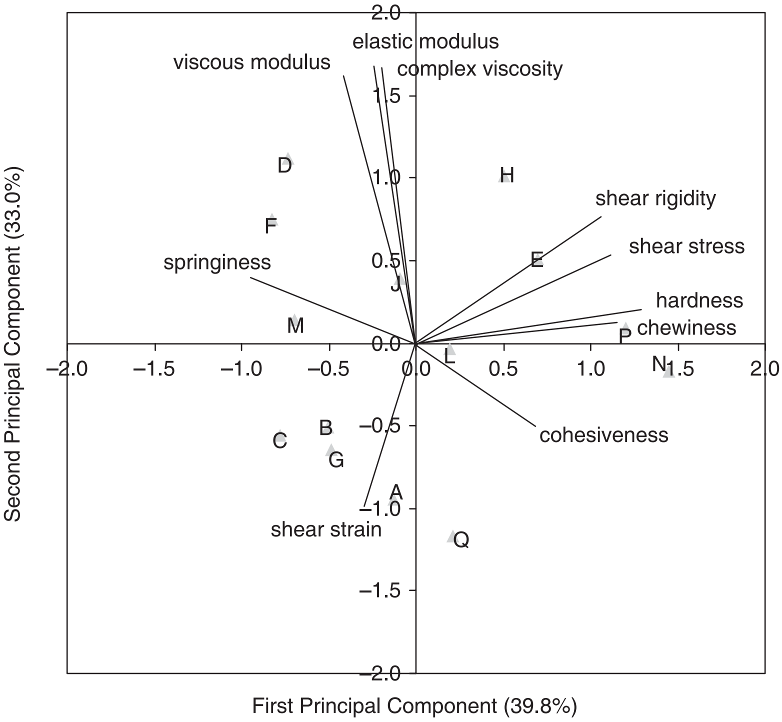

Figure 2 Principal component analysis biplot of brand variability among commercial Queso Chihuahuas made with raw milk (brands A to H, and J) or pasteurized milk (brands L to N, P and Q); vectors represent rheological properties.

0.92; and hardness and shear stress, 0.84). A biplot of the first and second principal components (Figure 2) showed the clustering of the different brands of cheese among the vectors for the rheological properties (related to the correlations between the properties). Three of the five PM brands of cheese were in the lower right-hand quarter of the plot with brand P just above this area. Brand P plotted near the chewiness vector, whereas brand L was located between the chewiness and cohesiveness vectors. The RM cheeses were scattered in the other three quadrants. Brands A, B, C and G were clustered at the lower left and were near the shear strain vector. Brands D, F, J, and M were in the upper left quadrant, with brand J plotted along the viscoelastic vectors and brand M near the springiness vector. Brands E and H were located in the upper right quadrant, with brand E plotted along the shear rigidity vector.

Two interesting items that come from the biplot were the placements of brands H, Q and M. Although brands H and Q are from the same manufacturer, the rheology of their RM and PM cheeses differ, as shown by the higher values for rigidity and viscoelastic properties of the RM cheese of brand H. In Figure 2, both brands plotted positive for the first principal component, but the RM cheese had a positive value for the second principal component, and the PM cheese had a negative value. Examination of the individual rheological properties (Table 2) showed that the brands had similar hardness, cohesiveness and chewiness values, whereas brand H had significantly higher shear stress, shear rigidity and viscoelastic properties than brand Q, thus illustrating the impact that the microflora present in the cheeses can have on their rheology. The other item of interest was brand M, the only PM cheese that did not cluster near the lower right quadrant of the biplot. Examination of its rheological properties (Table 2) showed that it was the softest (lowest shear stress and hardness values) and most flexible (highest shear strain and viscoelastic properties) of the PM cheeses. The causes for these differences need to be investigated further because of the lack of strong correlation between the rheological properties and cheese composition (data not shown).

Examination of the rheological properties of different brands of Queso Chihuahua showed considerable variation among the brands. Overall, cheeses made with RM or PM had similar ranges and overall means for composition and fracture properties. The main differences between the RM and PM cheeses were found in their TPA and viscoelastic properties. Of the cheeses in our data base that have been characterized using the same conditions and tests as described in this study, Queso Chihuahua was most similar in rheological properties to fresh Colby cheese.

Hispanic-style cheeses often are referred to as a specific style of ethnic cheeses but limited research has been performed to define how they are different from other types of cheeses. One way to define the cheeses and track differences in cheese is by their rheological properties. This study is the first to characterize Mexican Queso Chihuahua in terms of having specific fracture, compression and viscoelastic properties and reports the rheology baselines for the RM and PM cheeses at 10 days after manufacture. Establishing the cheese's quality traits is critical when examining manufacturing modifications that can improve the uniformity of the cheese, increase production, extend shelf life and ultimately expand utilization.

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